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RESEARCH AND DEVELOPMENT ON THE FIELD OF MINE DETECTION

Final Technical Report

Prepared by
GÜNTER WICHMANN
October 1996

United States Army

EUROPEAN RESEARCH OFFICE OF THE U. S. ARMY

London   England

Contract Number: DAJA 45 - 93 C - 0050

DTIC QUALITY INSPECTED

Contractor:

Development Office for Microwave Impulse Techniques
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1. Abstract

Due to the experience made over several decades in the field of mine detection it became obvious that the identification or at least the classification of detected objects will be indispensable because of the false alarm rate which would nullify the success of any mine detection system. This meant for a mine detector based on micro wave technology that additional information had to be gained by exploiting considerably higher frequencies than had been used in the past. Since, however, in wet soil high frequencies are subject to an extreme attenuation, a pulse radar system with an extremely clean pulse on an extremely clean baseline had to be built, especially investigating how the main clutter which is caused by the antenna and its interaction with the soil surface could be avoided.

By introducing a completely unconventional method for diminishing the radar cross section of the antenna this clutter could be reduced by almost two orders of magnitude, thus achieving a cleanliness of the pulse which had never been reached before.

Thus it became evident that the system-internal clutter can be reduced to a level which possibly will allow the future identification or classification of mines.

As, however, for a final mine detector an antenna line array is unavoidable and the antenna-internal clutter as well as the clutter generated by the multiple reflexions between soil and antenna will increase due to the larger number of antenna elements involved, an additional improvement has to be achieved in order to at least maintain or even increase the performance now achieved when using a complete line array.

2. Introduction and Overview of the Problem

When searching mines by means of micro waves nowadays the main problem is not the detection of objects than rather their identification or at least classification. In the case of almost any micro wave detection method, the extremely high attenuation of wet soil as a function of frequency has resulted in the past in using constantly lower frequencies down to approx. 150 mHz, since very often only their use led to sufficiently significant signal amplitudes. The lower the frequency the lower the attenuation and the clearer the signal.

The fact that only a YES/NO indication concerning the presence of an object could be achieved, but no information on the quality of this object had been available, was ignored or accepted as a compromise, hoping that the enormously growing possibilities of modern signal processing methods would some day help to solve the problem. Apart from the signals of a few very large anti-tank mines this never happened due to the relation of object size versus applied wavelength.

The sole possibility of identifying the detected objects consists in extending the usable frequency range from several hundred mHz to approx. 10 gHz. Due to the higher geometrical resolution then available in all three dimensions there is a chance to identify the objects.

This is clearly shown in Figs. 2.1a to 2.1f and 2.2a to 2.2f. Two transmitter pulses of different frequencies, viz. a 1 gHZ monocycle as shown in Fig. 2.1a, and a 2.7 gHz monocycle as shown in Fig. 2.2a, are directed to five different targets placed at a distance of 10 cm in front of the antenna in the laboratory:
1. M14, 2. rock, 3. rock, 4. 3" mine simulant, 5. rock (see Fig. 2.3). The Figs. 2.1b to 2.1f and 2.2b to 2.2f show their reflexion signal. Whereas the signals of the 1 gHz pulses show about 1.5 cycles and only differ in their amplitude, those signals of Fig. 2.2b to 2.2f differ significantly from each other, so that an identification under these laboratory conditions is clearly possible. It seems obvious that an identification of those mines even when buried in the field might become possible provided the high frequency components could be exploited. But the problem is when transmitting these frequencies they are - especially in heavy wet soil - subject to an enormous attenuation so that the tiny returning signals are often lower by orders of magnitude than the clutter consisting of the same frequency spectrum. When analysing the clutter sources there is only one component which cannot be eliminated, viz. the surface/surface clutter (clutter caused by reflexions from different surface areas or objects like rocks and vegetation and multiple reflexions among them). This clutter portion may be such strong in the case of rich vegetation or extremely rough surface (freshly ploughed fields) that it masks all other clutter sources. It can, however, be extremely low, e.g. smooth soil surface and poor or missing vegetation. In the latter cases the next higher clutter level, viz. that of antenna-internal reflexions and multiple reflexions between antenna and soil surface become dominant (see Fig. 2.4a, b, c). As these conditions often prevail the elimination of the aforementioned clutter sources is essential for the performance of a mine detector. This has been the decisive factor leading to the idea of building a pulse radar system using an antenna with a neglegibly low radar cross section thus avoiding multiple reflexions between soil surface and antenna and simultaneously reducing to a large extent the reflexions within the antenna and thus obtaining such a clean pulse which allows a signal/clutter ratio of 60 to 80 dB.
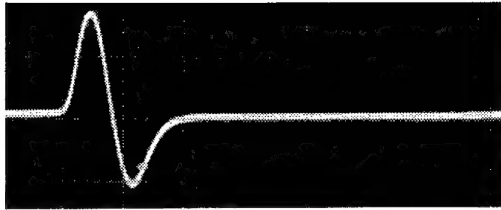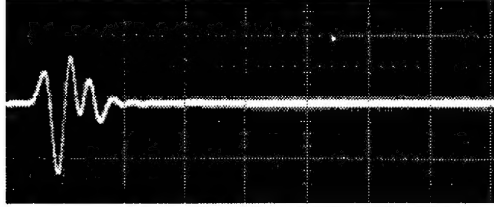
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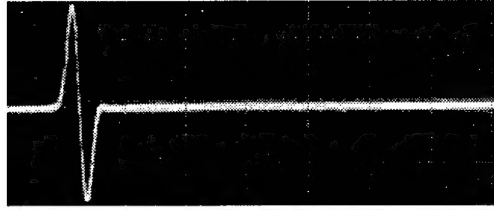
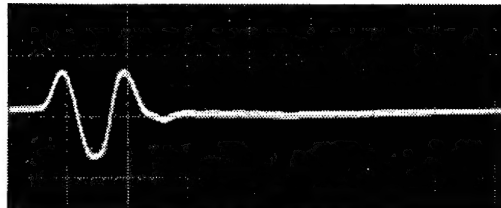2.2a y = 2 V/div.
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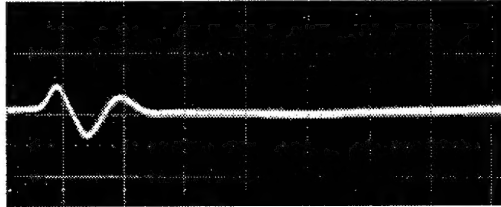
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         x = 500 pSec/0.85 div.

2.2b y = 50 mV/div.
         x = 500 pSec/0.85 div.

2.1c y = 50 mV/div.
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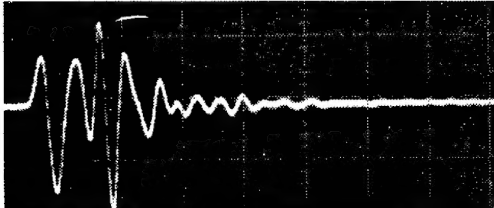
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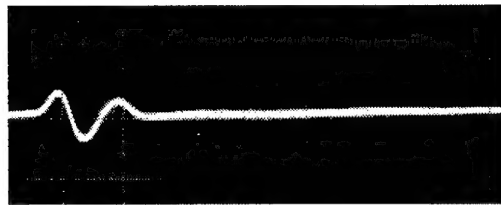
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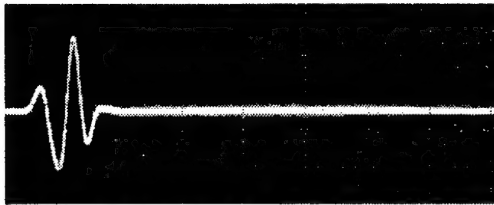
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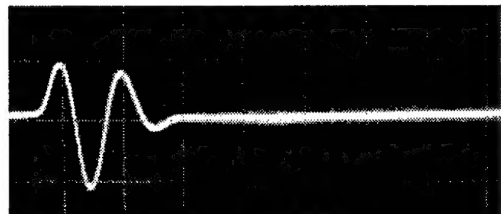
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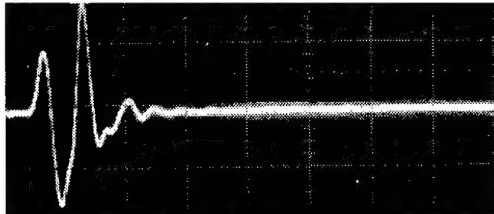
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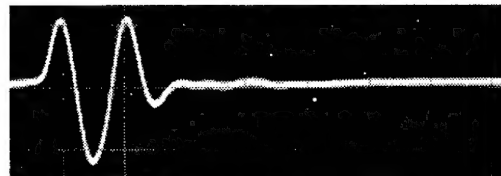
2.1f y = 100 mV/div.
         x = 500 pSec/0.85 div.
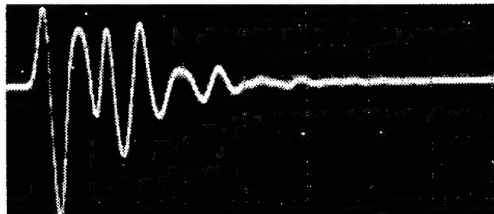
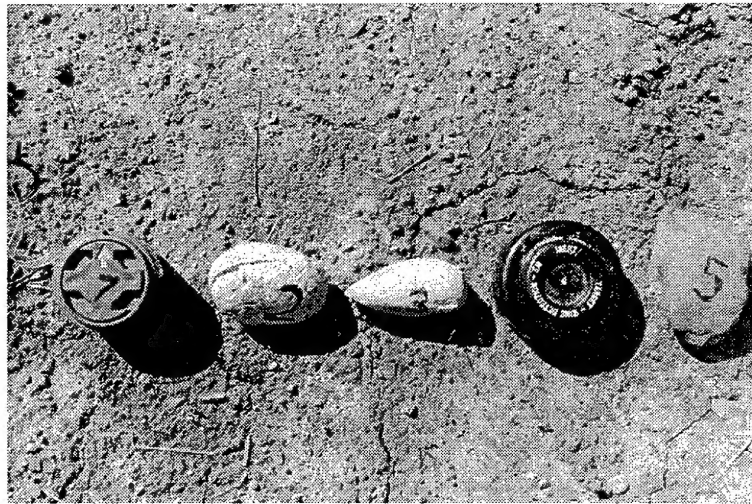2.2e y = 100 mV/div.
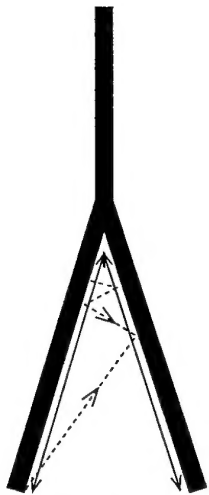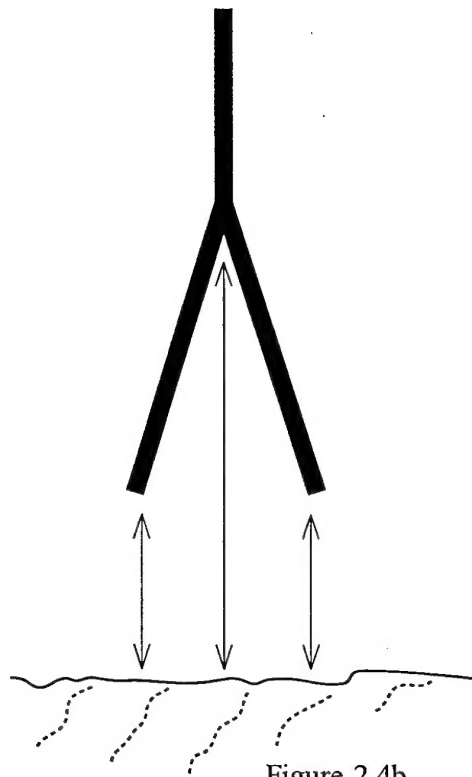   x = 500 pSec/0.85 div.
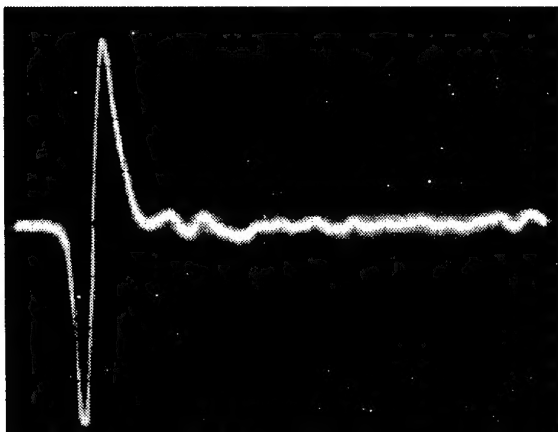
3

Figure 2.3

Figure 2.4a

Figure 2.4b

Figure 2.4c

3. Task Description

In order to make visible or to evaluate signals the amplitudes of which are 60 or even 80 dB below the surface return pulse, as it is the case in wet soil for the high frequency components, it became necessary to reduce all individual clutter sources in the total transfer chain to a level being even lower than the above mentioned value. This means, that it had been necessary to have the transmitting pulse so clean that the ratio pulse amplitude/system clutter amplitude and/or pulse amplitude/noise would become better than at least 60 to 70 dB, possibly however, even 80 to 90 dB.

Since the system clutter is caused by undesired reflexions and ringing in the different system components, all these individual clutter sources had to be reduced to the required order of magnitude. These are in the order of importance:

1. Antenna and multiple reflexion between antenna and soil

2. Receiver electronics

3. Transmitter pulse generator

4. Connectors

5. Coaxial cables

6. Other antenna cables

Moreover a total new electronics based on a concept matching the requirements concerning dynamic range and S/N ratio had to be realized.

4. Solutions and Results

4.1 Antennas and multiple Reflexions between Antenna and Soil Surface

Right from the beginning this item had been considered as the major problem and this for two reasons. First of all the clutter signals caused by these reflexions had been greater by 1 to 2 orders of magnitude when compared to those of all other sources and components respectively, with the exception of the surface/surface clutter. Second, their elimination seemed to be almost impossible. In order to eliminate the multiple reflexions between antenna and soil surface and/ or to attenuate them by at least several orders of magnitude, it had been necessary to make the antenna „invisible" in the micro wave band, i.e. to reduce its radar cross section possibly towards zero. Since this could not be achieved with a better form factor (stelth technology) only the disregard of many conventional laws and rules concerning an optimal antenna design for this special case led to a promising solution.

This included the acceptance of a very poor antenna gain as well as a bad impedance matching between antenna and pulse generator and/or antenna and receiver electronics.

For solving this problem right from the beginning antennas had been investigated which were made of little and non-metallic material arranged in such a manner that also its form factor led to a neglegible radar cross section.

The first preliminary tests had been carried out using dipoles where a push-pull pulse generator had been connected via two coaxial cables with two monopoles and a second pair of monopoles receiving the radiated pulse was connected via another two coaxial cables to a two-channel sampling oscilloscope which added and displayed the signals (see Fig. 4.1.1).
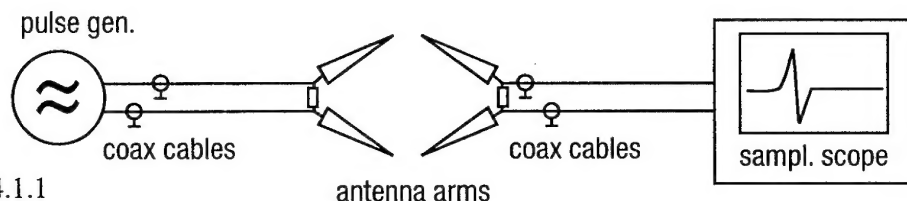

Figure 4.1.1

The material used was graphite or carbon-filled plastic foam (e.g. „Eccosorb"). Very soon the monopole elements were folded in forward direction in order to achieve a beam concentration. The original CRT photographs of this preliminary test are represented in Figs. 4.1.2a and 4.1.2b, the distance between transmitter and receiver antenna being approx. 5 cm and the S/N ratio amounting to only 35 dB due to the heavy noise of the sampling oscilloscope.

Fig. 4.1.2a shows the pulse shape using tapered antenna arms, Fig. 4.1.2b the pulse shape using antenna arms with a constant material thickness. The lack of cleanliless in the decay time is the result of reflexions within the antenna, in this case mainly end-tip reflexions. The antenna materials used at that time were too high in conductivity so that other solutions had to be found.

Using low-conductive graphite-coated threads proved to be very successful, one thread forming an antenna arm. These tests could no longer be carried out with the above described set-up since the antenna gain diminished drastically and signals were hardly visible any more. Only the set-up of a special sampling receiver providing an extremely high sensitivity offered the possibility of investigating very low-conductive antenna structures with respect to their internal reflexions and their radar cross section, since these antenna structures consequently have a very low antenna gain and therefore only very weak signals.

In the case of graphite-coated threads it was, however, almost impossible to vary the resistance distribution along the threads or the antenna arms respectively as it would have been necessary for the correction of the pulse shape. For this reason conductive foil material was chosen and cut into appropriate stripes forming the antenna arms. This offered the possibility to achieve all kinds of resistance distributions along the antenna arms by varying the width of those stripes.
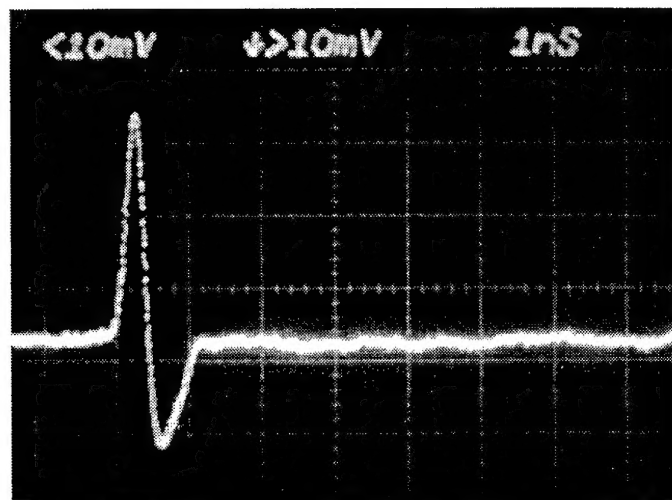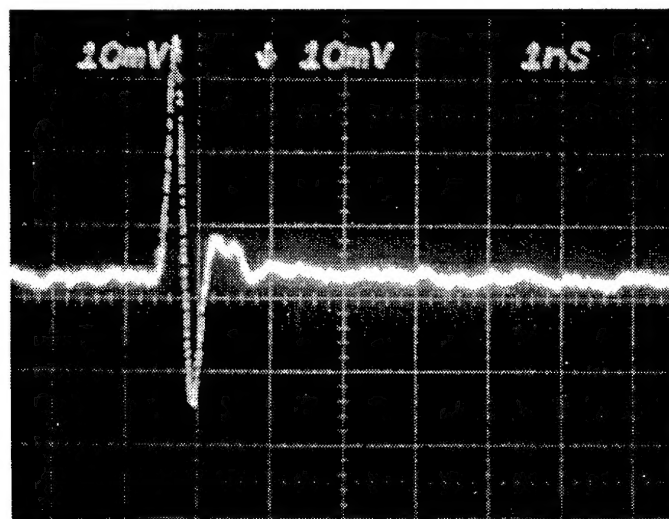
Figure 4.1.2a

Figure 4.1.2b

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4.2 Coaxial Cables, Plugs and Connectors

At the first go very clean pulses had been obtained using the graphite-coated threads as well as cut graphite foils, showing a signal/clutter ratio of about 40 to 50 dB. For a long time however there was no further progress until it was found out that the used coaxial cables represented a remarkable clutter source. Limited homogenity of these cables concerning their impedance along the line led to cable-internal reflexions. Especially the interaction of these internal reflexions with reflexions caused by poor impedance match between cable and antenna and/or cable and sampling receiver generated remarkable clutter signals. Even using completely new coaxial cable and very cautious handling to avoid any pressure or bend on the cable did not lead to the desired success. (By applying an intended amount of pressure with the fingers or a tool along the coaxial cable sometimes existing imperfections could be compensated.) This resulted in the incorporation into the antenna of transmitter pulse generator as well as of HF part of the receiver sampling system. Thus not only coaxial cables, but also plugs and connectors could be dispensed with, as their reflexions had also generated clutter.

Of course, the HF transmitter as well as the receiver electronics had to be designed so simple and small that their radar cross section became neglegible.

Figs. 4.2.1a to 4.2.1c show the performance achieved by these measures. Transmitter and receiver antennas are facing each other so that a reflexion plate was not necessary and the multiple reflexions mentioned several times could not occur. Fig. 4.2.1a shows the transmitter pulse at 2 volts/division, Fig. 4.2.1b the transmitter pulse at 10-times magnification and Fig. 4.2.1c the same at 100-times magnification, i.e. at 20mV/division. On these figures the horizontal deflection shows 500psec/0.85 division.
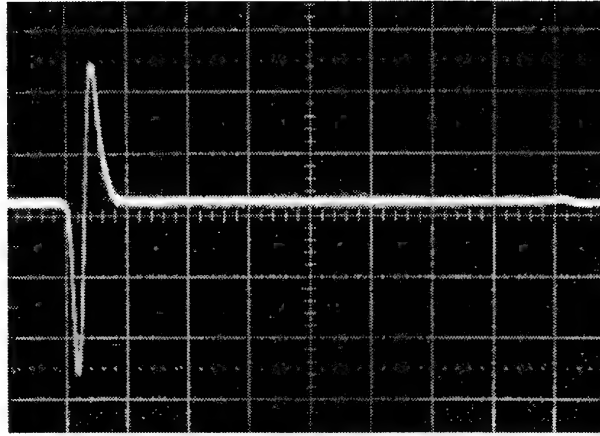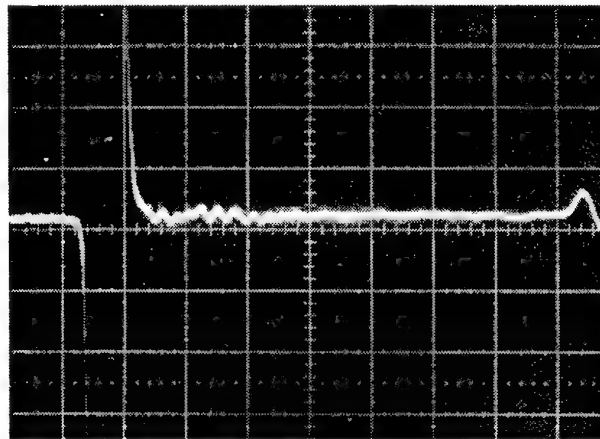

Fig. 4.2.1a y = 2 V/div.
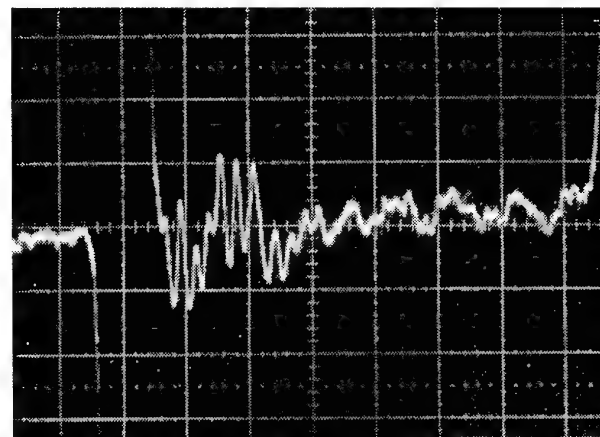x = 500 pSec/0.85 div.

Fig. 4.2.1b y = 0.2 V/div.
x = 500 pSec/0.85 div.

Fig. 4.2.1c y = 0.02 V/div.
x = 500 pSec/0.85 div.

4.3 Antenna-internal Reflexions and HF-Electronics

It can be read therefrom that during the first 1.2 nsecs. after the pulse the clutter amounts to about 40 mVp/p. Compared with 10Vp/p signal this amounts to about -48dB, then (second half of Fig. 4.2.1c) about 10 mVp/p, which corresponds to -60dB.

The reason for the clutter generated during the first 1.2 nsecs. had been antenna-internal reflexions (end-tip) as well as insufficient behaviour of the HF-electronics. One part of this could be eliminated, another part could be compensated. The following 10 mV clutter (in the second half of Fig. 4.2.1c) is generated by some transmitter energy which is picked up by the supply cables leading to the antenna. These supply cables form a waveguide system in which the picked-up energy travels along and is reflected by inhomogenities. By precisely arranging the supply cables the homogenity could be improved to an extent that the remaining clutter now amounts to about -70dB.

4.4 Antenna with 10 cm x 10 cm Aperture

The performance of this antenna can be clearly shown in a series of figures 4.4.1a to 4.4.1c.

It is the question of today's state of the art; deviating from Figs. 4.2.1a to 4.2.1c the transmitter and receiver anteanna is directed to a metal plate at a distance of 10 cm so that in addition to the system-internal clutter the multiple reflexions between antenna and metal plate become visible (approximately in the middle of the figure). The value of that clutter is scarcely 30 mV, i.e. about -52 dB.

The clutter generated during the first 1.2 nscs. has decreased to 20 mV - corresponding to -54 dB, that clutter shown on the second half of the figure is still at approx. -70 dB (see fig. 4.4.1c).

Fig. 4.4.1a y = 2 V/div.
x = 500 pSec/0.85 div.

The complete antenna group consists of three VEE antennas, i.e. one receiver and two transmitter antennas. The length of the antenna arms differs and amounts to 20 cm for the receiver antenna arranged in the center and to 17.5 and/or 22.5 cm for the transmitter antennas. The distance between the single antenna elements amounts to 5 cm (see Fig. 4.4.2). Whereas the 10 cm large apertures are on the same plane, the locations of the foot points differ due to the different lengths of the antenna arms. This is intended as the remaining reflexions from the foot points cannot add up but even cancel themselves
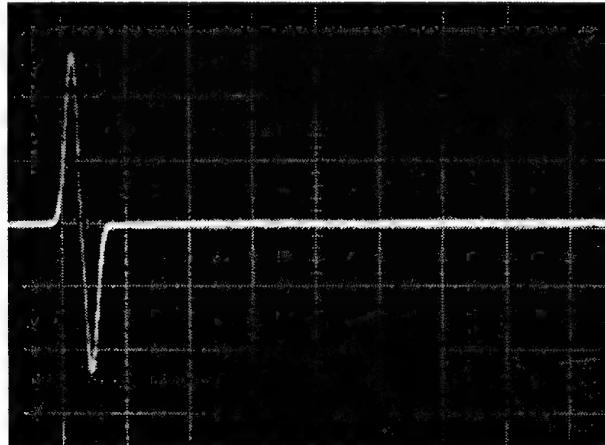

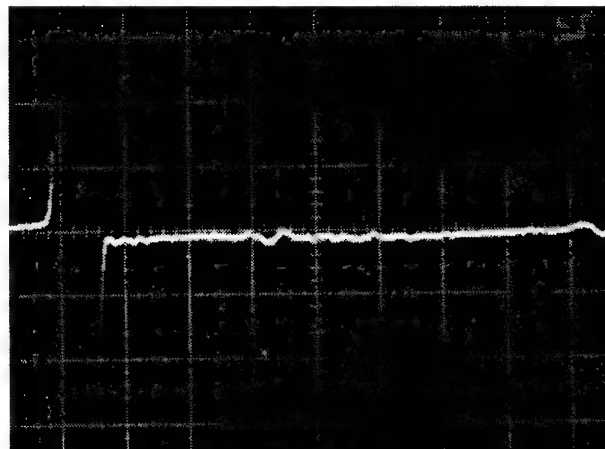Fig. 4.4.1b y = 0.2 V/div.
x = 500 pSec/0.85 div.

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partly due to interferential effects. Over the whole length the resistance of the antenna arms amounts to 2 kohms. The resistance distribution depends on the shape of the stripe and is chosen such that the resistance from the center to the foot point amounts to 700 ohms and from the center to the aperture to approx. 1.3 kohms. At the receiver output this compromise leads to a pulse shape which after having passed some filter network represents an ideal monocycle of approx. 2.7 gHz. Of course, the pulse shape is not the most important criterion for the characteristics of the antenna arms, but above all the antenna-internal reflexions, the radar cross section, the beam concentration in the near field and the signal/clutter ratio. For all these items, however, the chosen shape seems to be acceptable. Nevertheless in the future deviating findings are still imaginable or rather probable.

Fig. 4.4.1c y = 0.02 V/div.
x = 500 pSec/0.85 div.

Fig. 4.4.2

staggered
foot points

17,5 cm
(22,5)

20 cm
(25)

22,5 cm
(27,5)

There is another 10-cm antenna group which is used for experiments to eventually find still better results with regard to S/N and S/Cl ratios or beam concentration. For a long time, longer antenna arms had been used because they provided an improvement of the S/N ratio of about 4 to 6 dB. However, since a better beam concentration did not occur as expected and longer arms also necessitated an additional overall length of this antenna, this solution so far has not been pursued any further.

The achieved radar cross section can be illustrated on Figs. 4.4.3a and 4.4.3b. It is the question of the reflexions of a single VEE antenna placed 10 cm in front of the antenna of a complete radar system. The reflexions shown on Fig. 4.4.3a (400 mV) had been achieved when the two antenna arms were made of 1 mm thick silver wire, while those shown on Fig. 4.4.3b (20 mV) had been achieved when the antenna arms were made of the resistive material described above. The difference between both amounts to 26 dB. Comparing the reflexions of 20 mV to the return signal of the metal plate the difference amounts to approx. 54 dB. In addition, Fig. 4.4.3a clearly shows the multiple reflexions within the antenna. Whereas the main reflexion is caused by the foot point, the aperture reflexion is by approx. 20 dB lower. In Fig. 4.4.3c the metal antenna is arranged slant in the radiation field (see Fig. 4.4.3d) causing crosswise reflexions from the left antenna arm to the right one or vice versa. They are clearly visible in the transformation section between aperture and foot point reflexions. In the case of the antenna made of resistive material the antenna-internal reflexions should also be present, but their level is so low that it is far beyond the noise of -80 dB and thus they cannot be investigated.
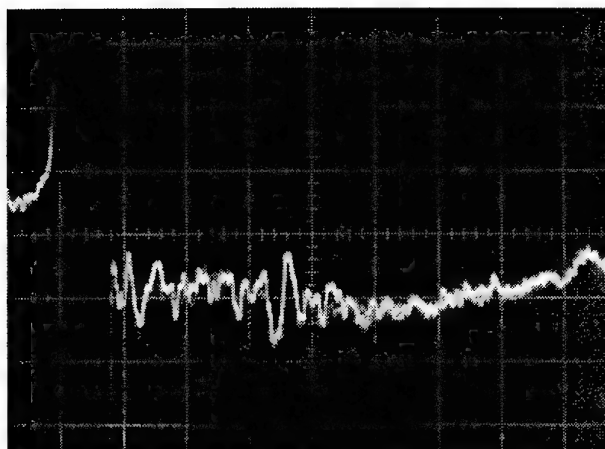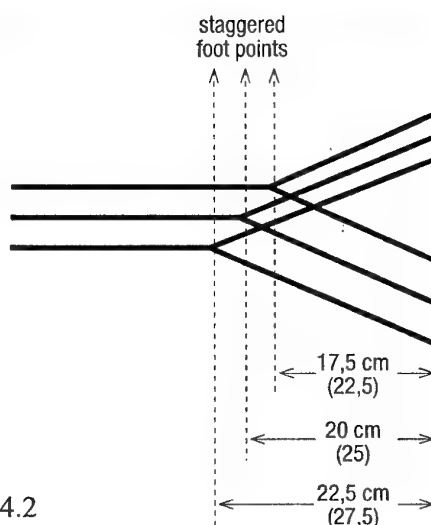
The impedance match of the antenna arms at the foot point is chosen such that the lowest possible reflexion was achieved. It is peculiar that an ideal impedance match could not be found with which the reflexion would approach almost zero, a fact which might be due to uncontrollable L and C portions. Fig. 11 shows the measured reflexion level peak/peak versus the matching resistance value in the case of metal antenna arms.
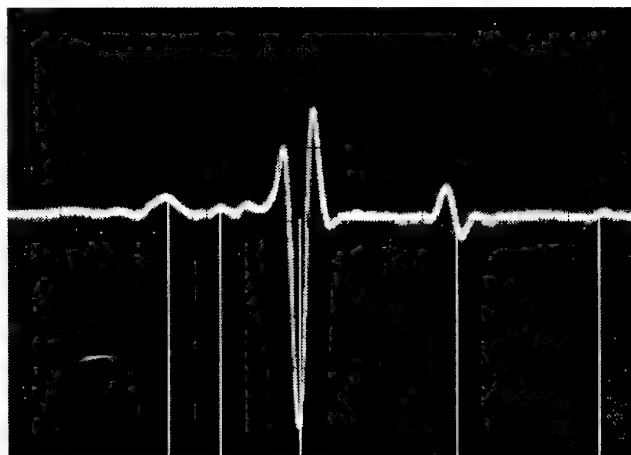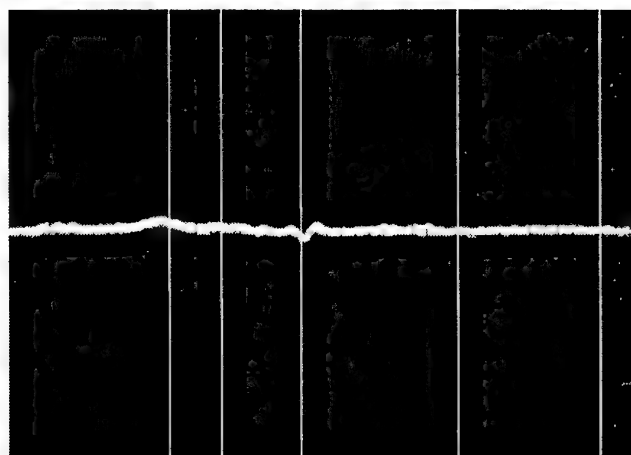

Fig. 4.4.3a y = 0.1 V/div.
         x = 500 pSec/0.85 div.

Fig. 4.4.3b y = 0.1 V/div.
         x = 500 pSec/0.85 div.
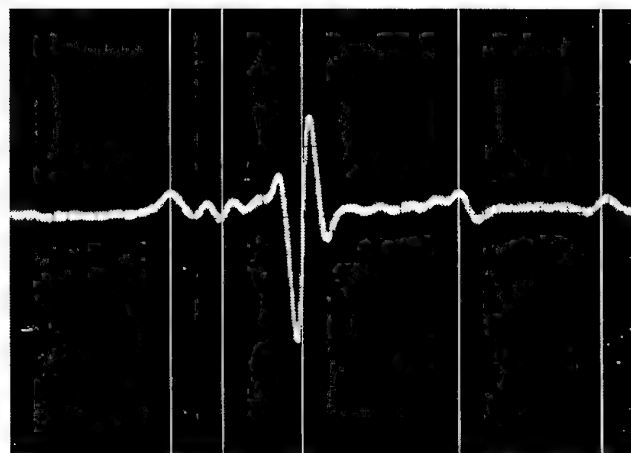
Fig. 4.4.3c y = 0.1 V/div.
         x = 500 pSec/0.85 div.

aperture   footpoint   multiple
                                         end tip
        transf.   end tip
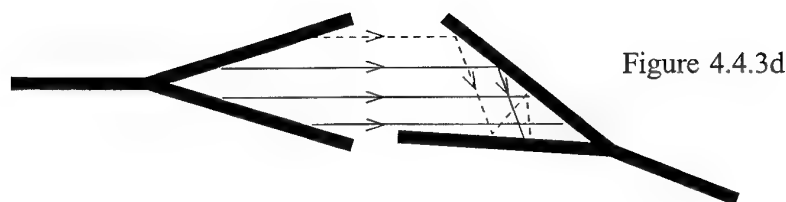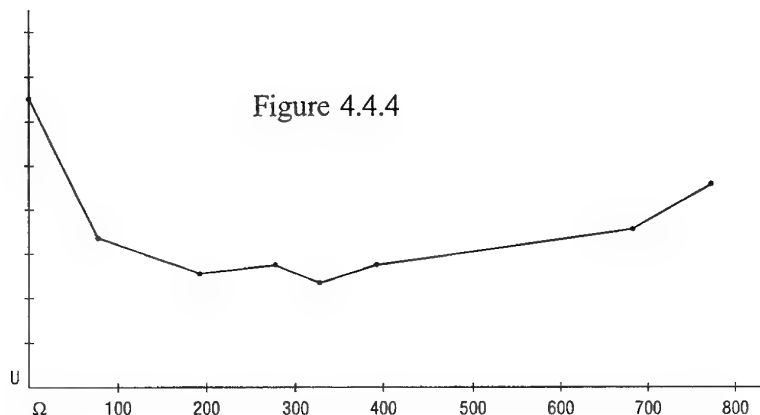   section   (aperture)

Figure 4.4.3d

Figure 4.4.4

4.5 Antenna with 5 cm x 5 cm Aperture

During field tests performed with small A/P mines, e.g. the M14 or the 3" mine simulant of Fort Belvoir, very soon it became obvious that under unfavourable conditions (dry sand) the ratio between mine signal and soil surface had been very unsatisfactory. To tackle with this fact an antenna was developed having an aperture of only 5 cm x 5 cm. This antenna also consists of one receiver and two transmitter elements, the receiver element being placed in the center. The length of the receiver antenna arms amounts to 22.5 cm and that of the transmitter antenna arms to 25 cm, their apertures again being arranged in the same plane.

It had been expected that by using this antenna the ratio of mine signal/surface signal would improve in favour of the mine signal. As can be gathered from the figures of section 6, this had been achieved, however, not as successful as was hoped since the improvement only occurred in the E-plane (see section 4.7). It was a surprise that the frequency response of this antenna and thus the transferred pulse shape had been almost identical with that of the 10 cm x 10 cm antenna. As can be derived from the measurement results of section 4.7 even the radiation characteristics were similar. Possibly the fact that all measurements were performed in the near field explains the measured behaviour.

When compared with the 10 cm x 10 cm antenna a clear disadvantage are the values of the S/N and signal/clutter ratios, both having decreased by approx. 12 dB, i.e. the S/N ratio for this antenna being approx. 68 dB and the signal/clutter ratio 58 dB. This is due to the fact that the system noise has remained unchanged and apparantly also the system-internal clutter arising from the transmitter power picked up by the antenna supply cables and reflected from there back to the antennas. At the same time the signal voltages are lower as the transmitter and receiver antenna areas represent only one fourth each of the 10 cm x 10 cm antenna. In spite of these reduced S/N and S/cl ratios this antenna seems to be sufficiently suitable for A/P mines. When used for anti-tank mines, however, the signal of which is essentially lower because of the possible considerably deeper placing of these mines and therefore of the increased soil attenuation, noise as well as clutter are not tolerable at all.

4.6 Present Shape of the overall Antennas

As was mentioned in section 4.3 the antenna supply cables contribute a lot to the remaining clutter and their special arrangement determines the overall length of the antenna (see Fig. 4.6.1a). Regarding the handling by an operator this shape is disadvantageous. For this reason it had been investigated soon whether or not a bent version would be possible. Although this bend leads to clutter as was expected, this clutter was tolerable when bend angle and bend radius had not been exaggerated. A later version could then be shaped as is shown in Fig. 4.6.1b. However, a later antenna version has to be extended to an antenna line array so that the final necessary shape cannot yet be decided.

Of course the use of absorbing material in the antenna supply cables also will have to be investigated in order to possibly achieve a better form factor.
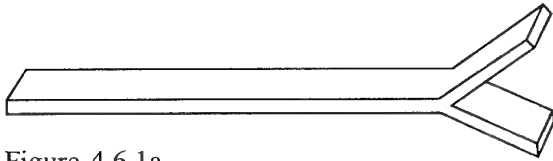
Figure 4.6.1a
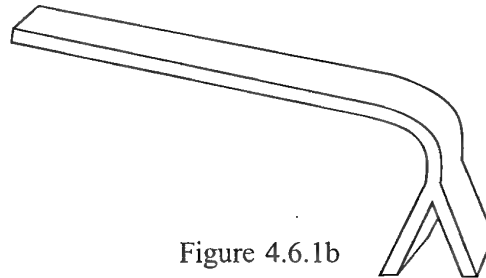
Figure 4.6.1b

4.7 Antenna Measurements and Behaviour of the overall System

4.7.1 Antenna Measurements

For measuring the beam divergency first a square target of a 5 cm edge length was placed at a distance of 5 cm in front of the antenna to be measured and was moved along a circle arc the center of which corresponded to the average of the different antenna foot points (see Fig. 4.7.1.1). As the averaged arm length was only 20 cm for the 10 cm antenna while being 25 cm for the 5 cm antenna, this led to different radia, viz. 25 and/or 30 cm. The measured amplitude peak/ peak was plotted as a function of the angle and standardized to one on the main radiation axis. The measurement results are represented on Figs. 4.7.1.2a and 4.7.1.2b. The bulge on the basis of the pattern in the case of the H plane of the 10 cm antenna might be caused by the lower distance to the foot point - when compared to the 5 cm antenna because of the smaller radius.

A second measurement, probably even more informative is that of the spot diameter of the radiated beam. For this measurement a metallized sphere of a 6 cm diameter was moved on a straight line crosswise to the radiation direction 5 cm and/or 10 cm in front of the antenna, and the reflexion amplitude in the H- and E-planes was plotted as a function of the location (see Fig. 4.7.1.3).

The measurement results of the 5 cm antenna are represented in Figs. 4.7.1.4a and 4.7.1.4b, the results of the 10 cm antenna in Figs. 4.7.1.5a and 4.7.1.5b. It becomes evident that at a distance of 5 cm the 5 cm antenna generates a clearly smaller spot diameter (3 dB-points) than that of the 10 cm antenna. At a distance of 10 cm, however, the 10 cm antenna is already slightly better. Fig. 4.7.1.6 shows the spot sizes and shapes (-3 dB) and the above mentioned statement becomes more significantly visible.
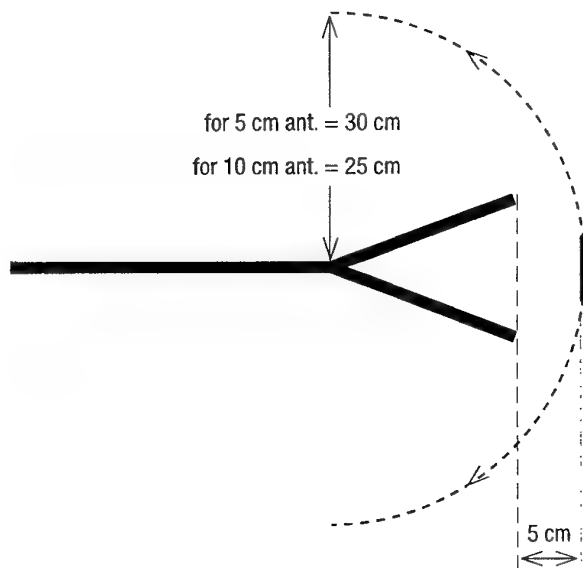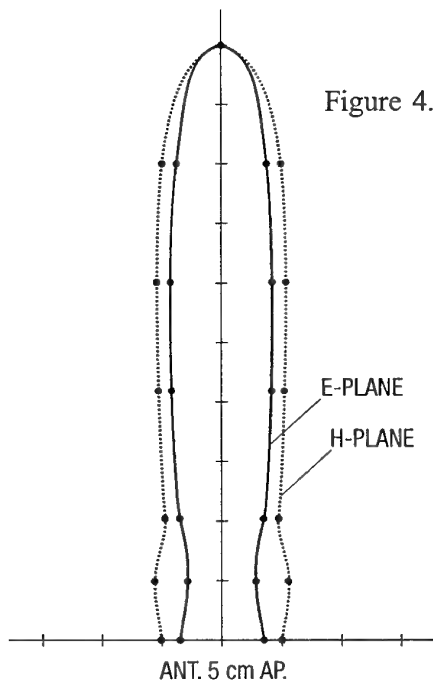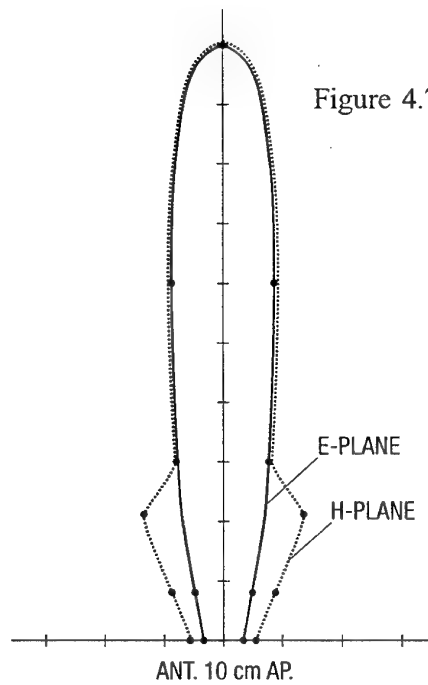
for 5 cm ant. = 30 cm

for 10 cm ant. = 25 cm

5 cm

Figure 4.7.1.1

Figure 4.7.1.2a

E-PLANE

H-PLANE

ANT. 5 cm AP.

Figure 4.7.1.2b

E-PLANE

H-PLANE

ANT. 10 cm AP.

5 and 10 cm resp.

Figure 4.7.1.3

1 4

3 dB points: E-plane = 7,5 cm
H-plane = 12,0 cm

Figure 4.7.1.4a

H-PLANE

E-PLANE

SMALL ANTENNA: 5 cm DISTANCE

3 dB points: E-plane = 12,0 cm
H-plane = 15,0 cm

Figure 4.7.1.4b

H-PLANE

E-PLANE

SMALL ANTENNA: 10 cm DISTANCE

15

3 dB points: E-plane = 10,25 cm
H-plane = 11,75 cm

Figure 4.7.1.5a

E-PLANE

H-PLANE

LARGE ANTENNA: 5 cm DISTANCE

3 dB points: E-plane = 13,75 cm
H-plane = 12,0 cm

Figure 4.7.1.5b

E-PLANE

H-PLANE

LARGE ANTENNA: 10 cm DISTANCE

1 6

SPOT SIZE OF SMALL ANTENNA (5 cm)

H = 12 cm

E = 7,5 cm

5 cm distance

H = 15 cm

E = 12 cm

10 cm distance
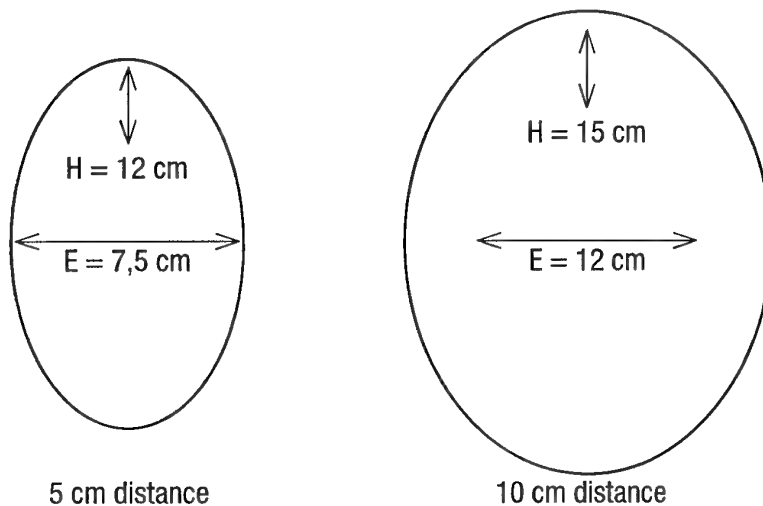
Figure 4.7.1.6

SPOT SIZE OF LARGE ANTENNA (10 cm)

H = 11,75 cm

E = 10,25 cm

5 cm distance

H = 12 cm

E = 13,75 cm

10 cm distance
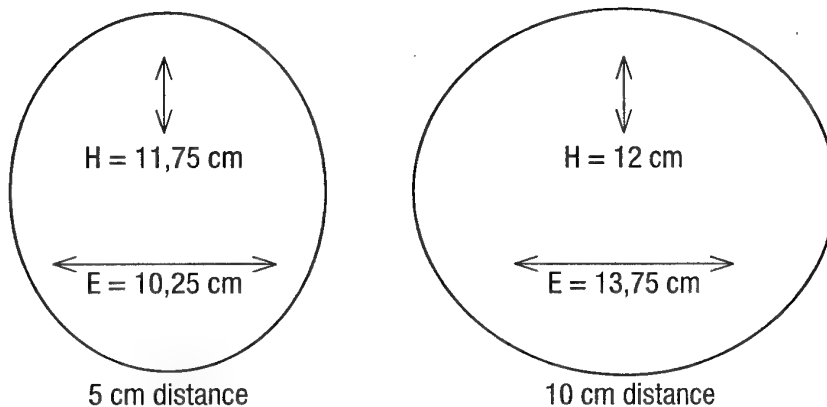
4.7.2 Behaviour of the overall System

The shape of the pulse after having passed the whole transfer chain - transmitter, antenna, reflecting metal plate, receiver, LF amplifier plus filters - was already depicted in Figs. 4.4.1a to 4.4.1c. If this pulse is directed to targets having a distinct self resonance like rings made of silver wire with different diameters, the frequency response can be determined sufficiently precise by recording the reflected amplitudes. Fig. 4.7.2.1a to 4.7.2.1e shows the reflexion signals of several rings having a self resonance of 0.5 gHz, 1 gHz, 2 gHz, 4 gHz and 6 gHz. After a correction of the measured values corresponding to the differing ring diameters and thus to the reflective areas the frequency response of the system can be derived therefrom (see Fig. 4.7.2.2). When assessing the resulting transfer function it has to be taken into account that the S/N ratio of the system is better than 80 dB, i.e. that even in the case of 0.5 gHz and/or 7.5 gHz a S/N ratio of better than 60 dB is still available. As already mentioned before the system shows the same overall frequency behaviour in the near field independently of the antenna used, except for the S/N and S/cl ratios which are worse by approx. 12 dB in the case of the 5 cm antenna.
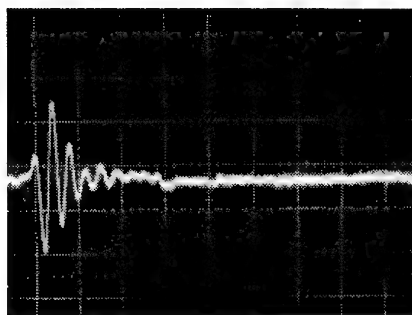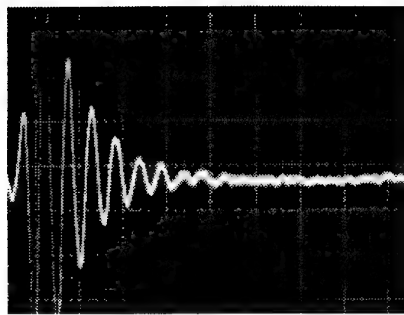
Fig. 4.7.2.1a
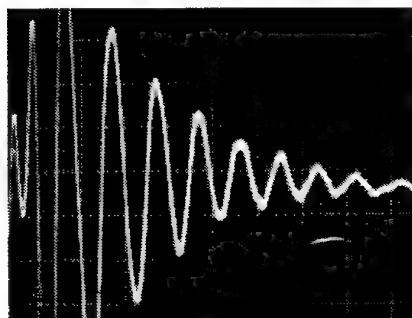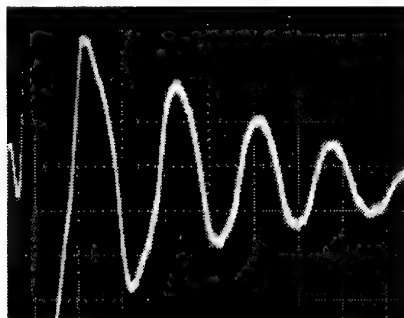6 GHz

Fig. 4.7.2.1b
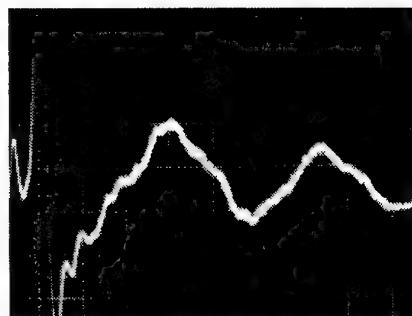4 GHz

Fig. 4.7.2.1c
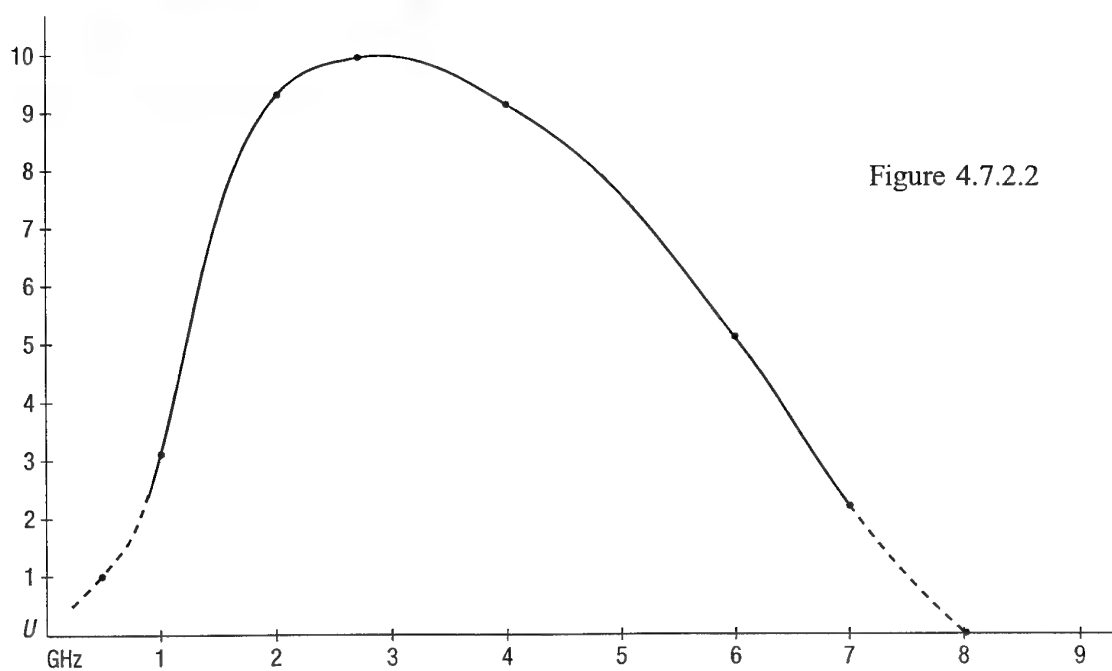2 GHz

Fig. 4.7.2.1d
1 GHz

Fig. 4.7.2.1e
0,5 GHz

Figure 4.7.2.2

5. Electronics

Fig. 5.1 shows the block diagram of the electronics consisting of five subassemblies, the heart of which is a Printed Circuit Board (PCB) containing sampling, clock, drive and control electronics. This PCB includes a 16 mHz master generator in form of a quartz oscillator from which all other necessary clock frequencies are derived. From there HF trigger and control signals are fed into the antenna for releasing the transmitter pulse generator as well as the sampling strobe pulses because the antenna accommodates this transmitter pulse generator and the sampling HF unit as well as a LF frequency amplifier for the amplification of the signal voltage. Transmitter and receiver electronics are integrated into the foot points of the respective antennas in a miniaturized version.

The LF signal is led from the antenna to the preprocessor PCB which primarily contains filter networks und serves for pulse shaping. From here the signal is fed to a PCB forming the crosstalk memory. In order to cancel the crosstalk between transmitter and receiver antenna, the crosstalk function is stored by pressing a push button. To do this, the antenna has to be held in a position in which within a 1 m distance no object ought to be present. The stored function will then be substracted from the actual signal so that crosstalk signals are cancelled. This substraction is also done in the crosstalk memory. Thereafter the signal returns to the preprocessor from which it reaches the output after having passed another filter to eliminate eventually existing D/A converter spikes. To display the resulting signals a laboratory oscilloscope must be used. These three PCB's are accommodated in a 24 cm x 24 cm x 13 cm housing together with another PCB containing the power supply.

The input voltage range amounts to 100 up to 240 volts +10/-15% and the frequency range to 47 up to 63 Hz. The power consumption presently amounts to about 15 watts. Fig. 5.2 shows the overall equipment including the two antennas.
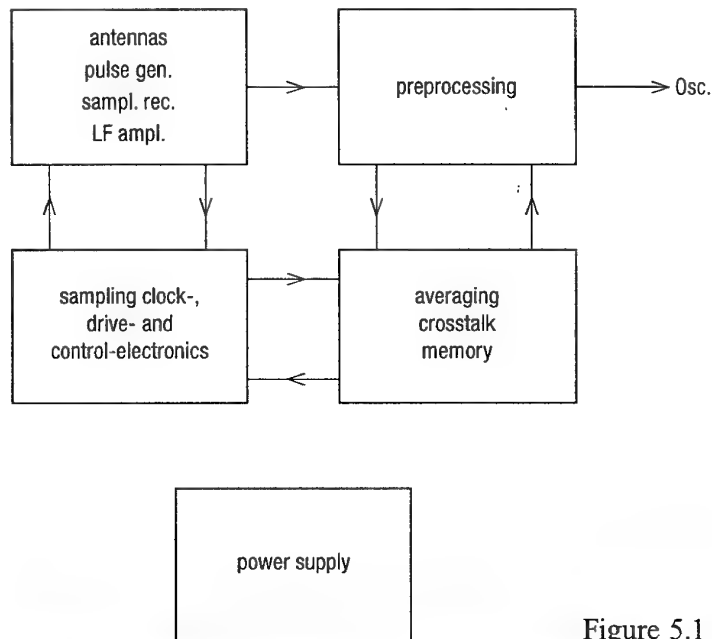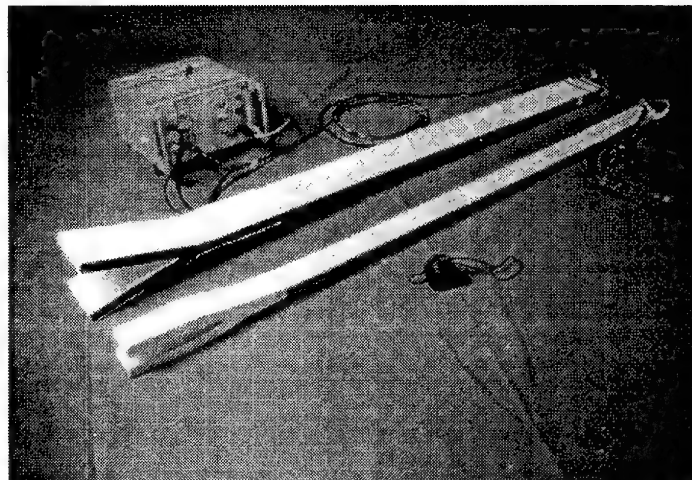

Figure 5.1

Figure 5.2

# 6. Field Measurements and Discussion

The following mine types and/or mine simulants were available: A 6" and a 3" mine simulant, a butterfly mine and an M14 from Fort Belvoir, a PPM2 from the former GDR and in addition an old TMDB (AT mine) and a MATS (25 cm AT mine). The reflexion signals of the first five targets having been taken in open space in the laboratory are shown in Fig. 6.1a to 6.1e. Therefore these five mine types had been placed at a distance of 10 cm in front of the antenna.
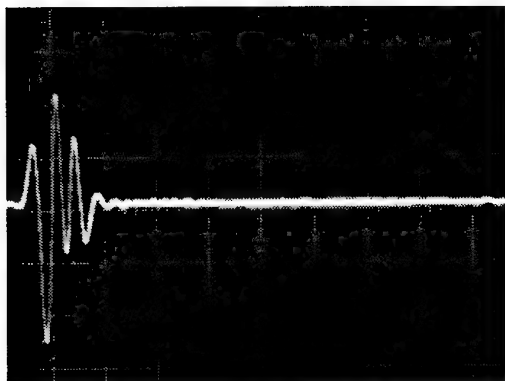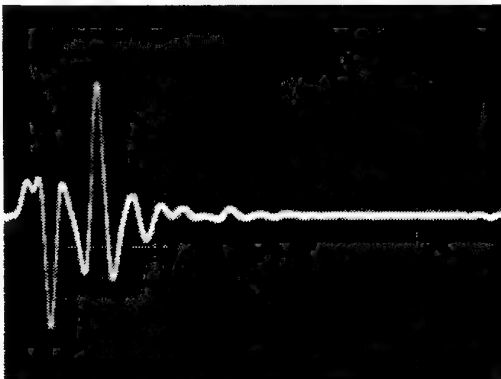

6.1a M14   y = 0.05 V/div.
              x = 500 pSec/0.85 div.
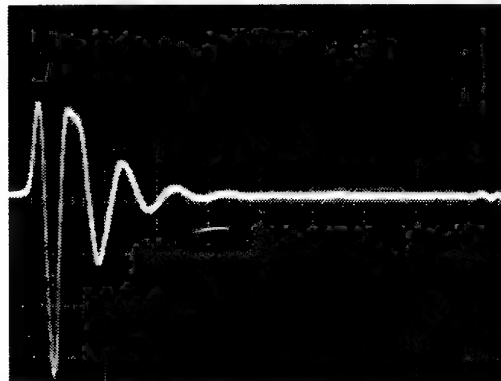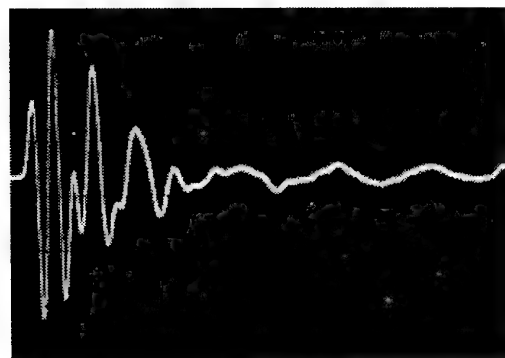

6.1b Butterfly   y = 0.1 V/div.
              x = 500 pSec/0.85 div.
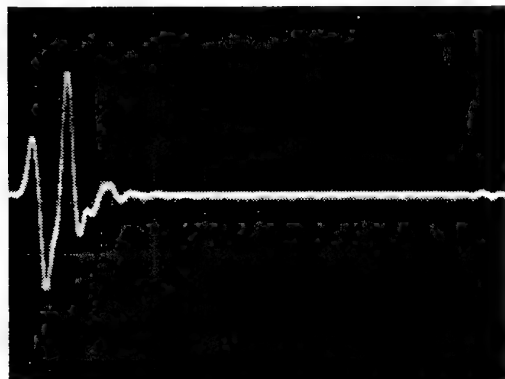
6.1c 3" Simul.   y = 0.1 V/div.
              x = 500 pSec/0.85 div.

6.1d 6" Simul.   y = 0.2 V/div.
              x = 500 pSec/0.85 div.

6.1e PPM-2   y = 0.1 V/div.
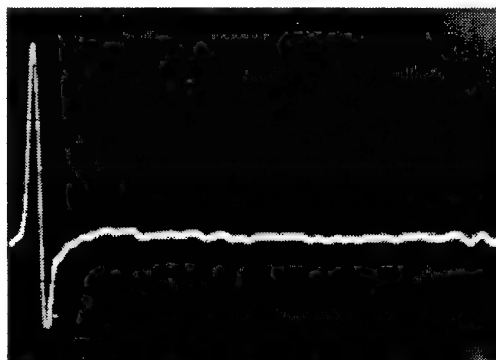   x = 500 pSec/0.85 div.

During several outdoor tests these mines were then buried in the soil. The AP mines were buried in dry sand representing a very difficult case because the epsilon of dry sand can almost equal that of the mine resulting in very poor reflexion signals. The 6" mine simulant representing one of the smallest anti-tank mines and thus one of the most difficult to be detected and the TMDB and MATS were buried in varying wet, loamy soil in different depths.

Some typical signals are shown in the following figures. Fig. 6.2a shows the surface return signal of loam and Fig. 6.2b that of dry sand with the 5-cm antenna, Fig. 6.2c the loam surface return and Fig. 6.2d the sand surface return with the 10-cm antenna. While the signals of Figs. 6.2a and 6.2c were achieved when the moisture content was varying from about 3 to 14 per cent with increasing depth, the return signal of Fig. 6.2e was taken when the loam had a constant moisture content of 23 per cent. Figs. 6.3a to 6.3d show the return signal of an M14 buried 1 cm and 7 cm deep, respectively, in dry sand with the two different antennas. Fig. 6.4 again shows the signal of an M14 - 1 cm deep - on another day with the 5-cm antenna. While the upper trace represents the normal 2.7-GHz signal, the lower trace shows the return signal of the same situation using a 1-GHz pulse. Fig. 6.5 shows the signal of a 3-inch mine simulant 1 cm deep, and Fig. 6.6 shows (in front of the surface return) that of a butterfly mine on top of the dry sand with the metal rod positioned crosswise to the E-field. All three signals are clearly visible and distinguishing features can easily be recognized on the upper trace, i.e. with the 2.7-GHz pulse. With the 1-GHz pulse there is no useful difference in the three signals.
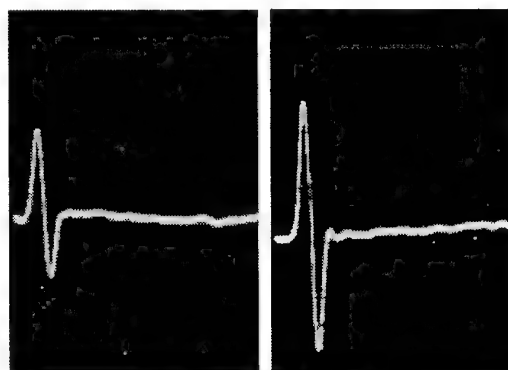
The same applies to Fig. 6.7, which again was an M14 buried 1 cm deep in dry sand. The 1-GHz return signal doesn't give any indication of the mine.
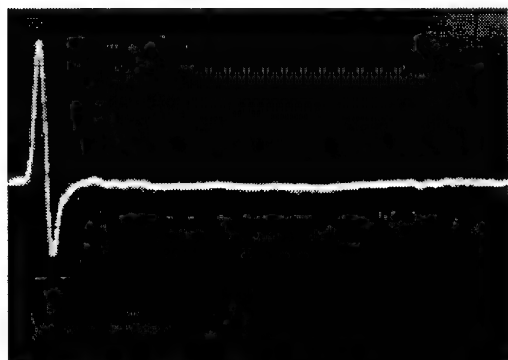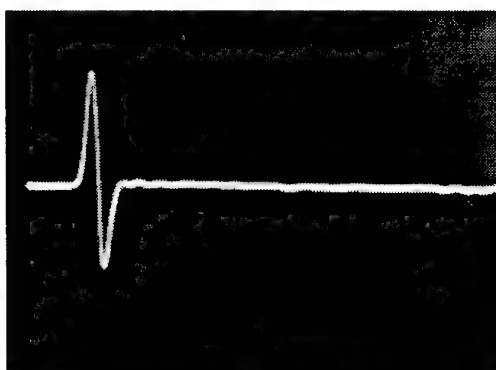

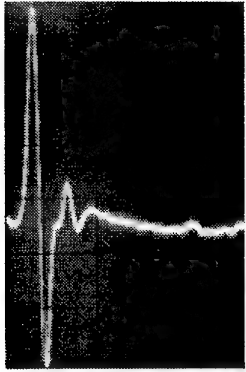6.2a y = 0.5 V/div.   5cm ant.
      x = 500 pSec/0.85 div.

6.2c y = 0.5 V/div.   10cm ant.
      x = 500 pSec/0.85 div.

6.2b 5cm ant.   6.2d 10cm ant.
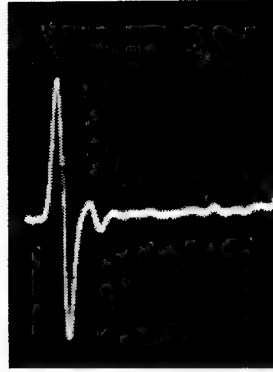   y = 0.5 V/div.
    x = 500 pSec/0.85 div.

6.2e y = 1 V/div.   10cm ant.
      x = 500 pSec/0.85 div.
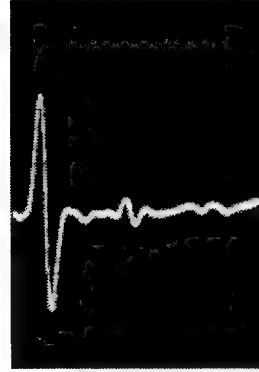
6.3a   0.2 V/div.
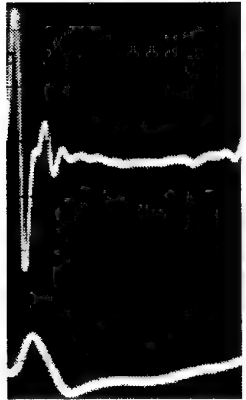   5cm ant.

6.3b   0.2 V/div.
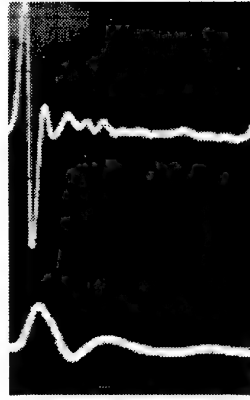   5cm ant.

6.3c   0.5 V/div.
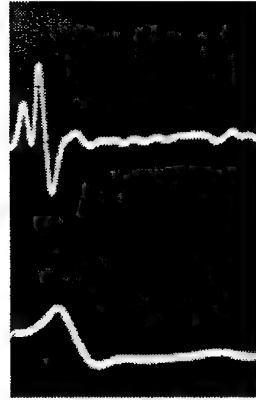   10cm ant.
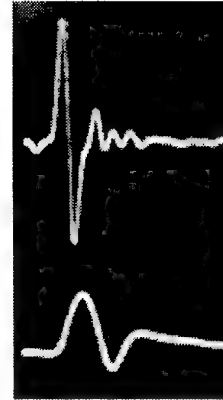
6.3d   0.5 V/div.
       10cm ant.

6.4   0.2 V/div.
       5cm ant.
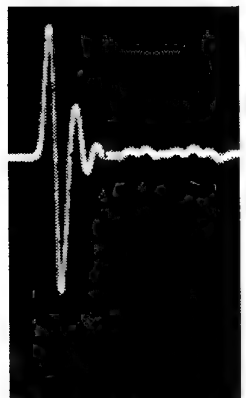
6.5   0.2 V/div.
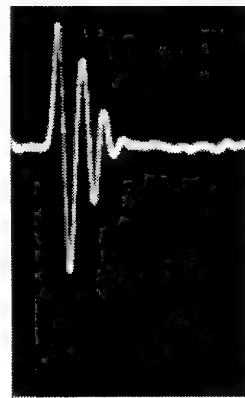   5cm ant.

6.6   0.2 V/div.
       5cm ant.

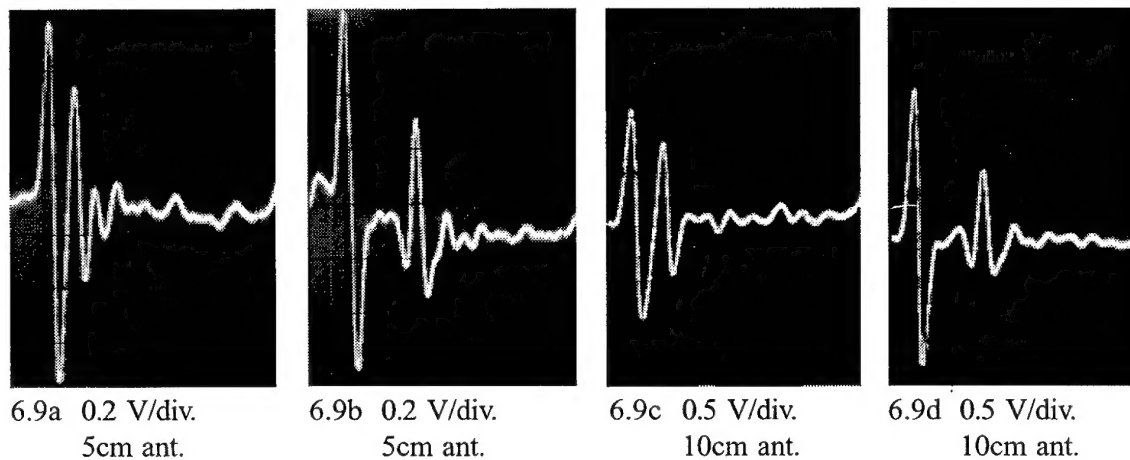6.7   0.2 V/div.
       5cm ant.

6.8a   0.5 V/div.
       10cm ant.

6.8b   0.2 V/div.
       5cm ant.

Figs. 6.8a and 6.8b show the difference between 5-cm and 10-cm antenna in another situation, when the sand was slightly moist (approximately 1.5 per cent of water) and an M14 was buried about 2 mm (!) deep. A big difference in signal amplitude appears in favour of the 5-cm antenna, since its spot diameter matches the diameter of the small mine to a better extent. The large AP mine of the type PPM-2 which has a diameter of approximately 12 cm again barried 1cm and 7cm deep shows very strong signals with both antennas, although the 5-cm antenna provides even more details (see Figs. 6.9a to 6.9d).

| 6.9a 0.2 V/div. | 6.9b 0.2 V/div. | 6.9c 0.5 V/div. | 6.9d 0.5 V/div. |
| 5cm ant. | 5cm ant. | 10cm ant. | 10cm ant. |

Figures 6.10a to 6.10d show the reflection signals of the 6-inch mine simulant representing a very small antitank (AT) mine. A very detailed signal is obtained when the mine is buried 7 cm deep in relatively dry loam having only 5 per cent water (Fig. 6.10a). With the mine buried 8 cm deep in loam with 21 per cent water, its signal decreases by approximately 10 dB (Fig. 6.10b). Figures 6.10c and 6.10d show the same object also 8 cm deep, but with 23 per cent water content of the soil, detected by the 10-cm and 5-cm antenna, respectively. Even the 5-cm antenna shows a detailed signal except for a worse low-frequency clutter on the base line. Looking at the different signals, the observer undoubtedly can discern a similarity allowing him to tell this target from another one.

One such other signal is shown in Fig. 6.11a. It is the signal of an old TMDB buried 10 cm deep in loam with 14 per cent water. The same signal taken a few days later at a slightly higher moisture content (16 per cent) looked like Fig. 6.11b, upper trace, the lower trace showing the signal caused by the 1-GHz monocycle. Fig. 6.11c shows the same signal received by the 5-cm antenna. Fig. 6.11d again shows the same target, but 11 cm deep in loam with 19 per cent water. At a first glance it seems to provide a different shape, but if one ignores the first half-cycle, some similarities with the shapes of the other signals become visible (upper traces only).

Another difficult signal is that of the MATS antitank mine which is shown in Figs. 6.12a and 6.12b with the mine buried 13 cm deep in loam containing 21 per cent of water. Being approximately 40 dB below the surface return and only 10 dB above the clutter in Fig. 6.12a, the signal amplitude of only about 100 mV is already very poor but still shows a typical behavior of this mine: its signal consists of only one monocycle, thus differing clearly from the signals of the other mines.
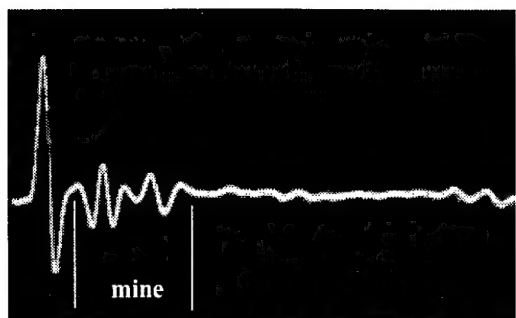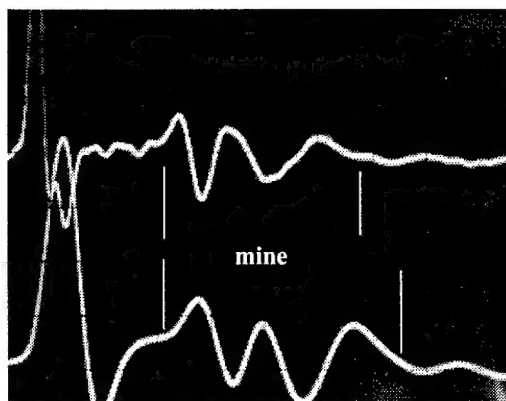
6.10a   y = 0.5 V/div.   10cm ant.
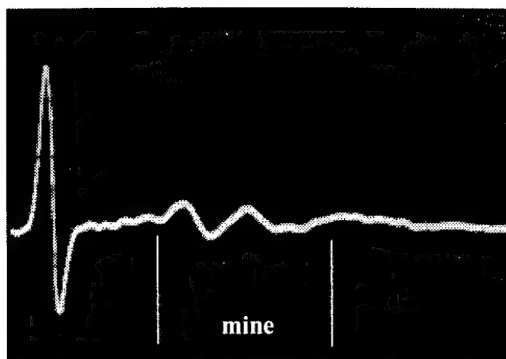
6.11a   y = 0.5 V/div.   10cm ant.
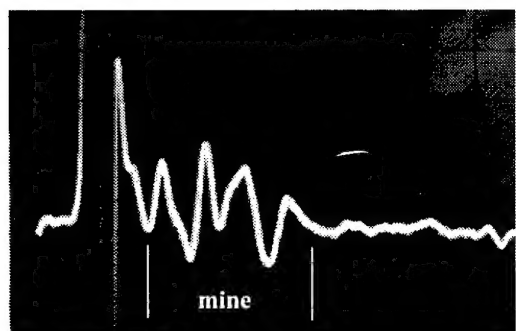
6.10b   y = 0.1 V/div.   10cm ant.

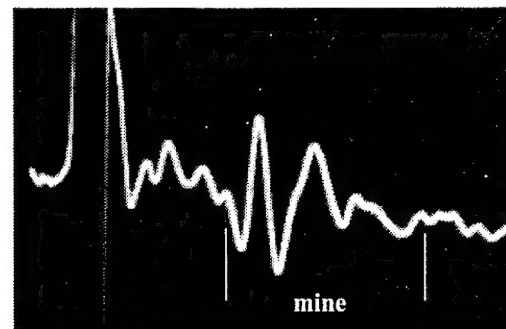6.11b   y = 0.2 V/div.   10cm ant.
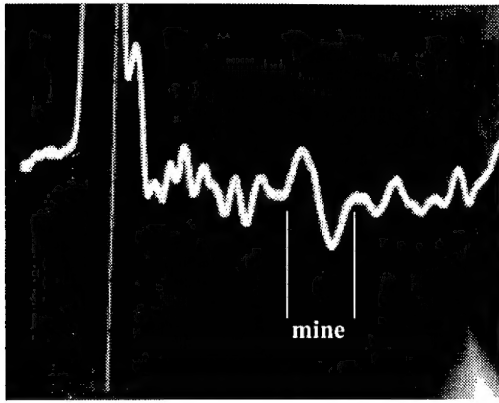   y = 0.5 V/div.   10cm ant.
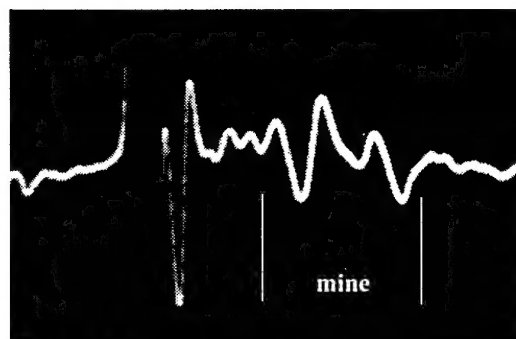
6.10c   y = 0.1 V/div.   10cm ant.
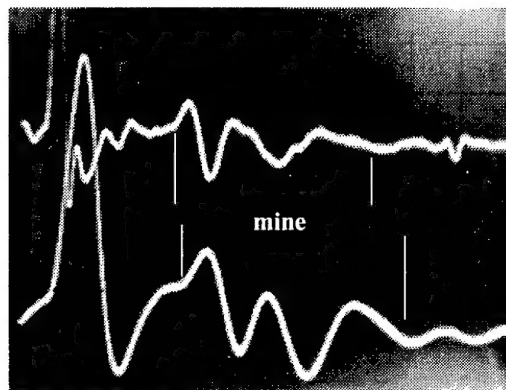
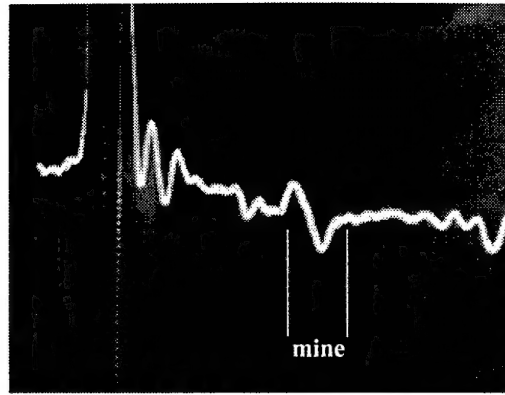6.11c   y = 0.1 V/div.   5cm ant.
         y = 0.2 V/div.   5cm ant.
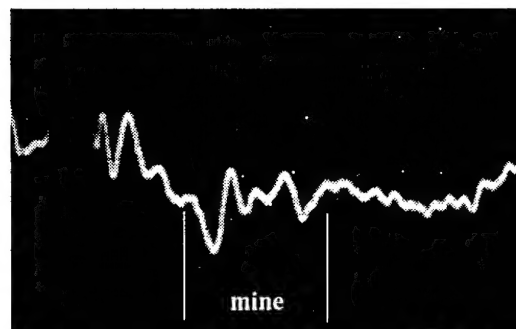
6.10d   y = 0.05 V/div.   5cm ant.

6.11d   y = 0.1 V/div.   10cm ant.

6.12a   y = 0.05 V/div.   10cm ant.

6.12b   y = 0.1 V/div.   10cm ant.

If analyzed, these AT mine signals provide good chances for identification in many cases because frequency components up to 2 or 3 GHz are available even if objects are searched in loam with a moisture content of more than 20 per cent. This was never possible before.

But since this type of soil can take up to 30 per cent of water, this high-frequency signals could more and more fade away and therefore the availability of the lower-frequency components down to 1 GHz or even .5 GHz must also remain guaranteed.

For a handheld mine detector, however, AP mines are the most dangerous ones because they threaten the lives of the operators; their detection and identification is particularly important. Looking at their signals, one could get the impression that this goal has already been achieved. However, this is not true because of the numerous manifestations of clutter signals caused by roughness as well as dips and bumps of the surface. Therefore exploitation of higher frequencies becomes indispensable, because the higher the frequencies are, the more details of the inner structure of the mine become available and probability of identification increases.

7. Conclusions and Recommendations

Although the ratio of signal to system-internal clutter as well as clutter caused by the interaction between antenna and soil surface has been improved by more than two orders of magnitude and therefore an impulse cleanliness is availabe now which was never believed possible before, several improvements are still necessary in view of the monstrous difficulties encountered in real situations.

For the identification of AP mines it is indispensable to further reduce the pulse length in order to increase the band width towards higher frequencies and to obtain a higher geometric resolution. This measure will have two effects: it will help to further reduce the spot size in front of the antenna and it will provide more details of the properties of the mine, which in turn will help to distinguish between mine signals and clutter signals caused by surface irregularities.

However, when increasing the band width towards higher frequencies, one has to take care not to give away the lower-frequency performance because in some extreme situations, e.g. when dealing with very wet or even almost saturated soil, it is still needed.

Analysis of some of the AT mine signals taken when the targets had been buried in moist soil makes evident that another remarkable increase in attenuation as it would be caused by a higher water content or deeper placing could diminish the signal amplitudes to a value which would disappear in the clutter. Since in this case it is a question of surface/surface clutter, besides exploitation of the lower-frequency content only a better beam concentration (side lopes) or an adaptation of spot diameter to target size could help to improve the situation.

The fact that the possibility of analyzing the high-frequency components of the return signals (resonance features) was given a very high emphasis in this report, does not mean that this is believed to be the solution of the problem. It is only **additional** information about the object. But exploitation of higher frequencies also can lead to better imaging with higher resolution, which is another, maybe even more promising way to solve the problem of target identification. In order to achieve all this, the development of an antenna line array will become necessary to provide a two-dimensional or even three-dimensional signal distribution of the targets. Such an array could also help to adapt the aperture size of the antenna to the target, if a compromise of the aperture size cannot be found. This can be done by exciting only one antenna element or group, e.g. for an AP mine, or a few adjoining elements or groups at the same time to match an AT mine. This array could as well contain several antenna arrays of different antenna sizes which then could be selected to match a particular object size. In any case, all possibilities will have to be investigated and the resulting information will have to be displayed either by using the intensity (grey shades) of the return signals directly or by forming images using the results of different signal processing methods, like e.g. spectrum analysis. It will also be worth while rendering the signal processing results audible.